



Lidar mapping and surface survey of the Izapa state on the tropical piedmont of Chiapas, Mexico

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ABSTRACT

Recent lidar and pedestrian surface surveys have remapped the well-known Mesoamerican site of Izapa and the surrounding Soconusco piedmont. These data document: 1) occupation from the surrounding piedmont environment, 2) significantly larger estimates of the site's size during both the Formative and Classic periods as well as 3) new architectural features from the monumental site core. Methodological issues are outlined for combining high precision lidar mapping with ground truthing and pedestrian survey that focuses on surface collection of temporally diagnostic artifacts. Results are presented for 670 mounds documented in an area of 43.1 sq km in and around the ancient capital of Izapa.

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1. Introduction to lidar mapping and Mesoamerican settlement patterns studies

Remote sensing technologies such as lidar (light detection and ranging) have a clear appeal to archaeologists as they can penetrate vegetation cover and map architectural features below. In 2011, for example, three articles were published on the topic in JAS (Chase et al., 2011; Ladefoged et al., 2011; McCoy et al., 2011), four were published in 2012 (Bollandsås et al., 2012; Dorshow, 2012; Stular et al., 2012; Verhagen and Dragut, 2012), and more are in press. Mesoamerican archaeologists have been given a taste of how effective lidar mapping can be by recent work at Caracol in western Belize and Angamuco in central Mexico (Chase et al., 2011, 2012; Fisher et al., 2011). Mapping 200 sq km around the Maya center of Caracol demonstrated how quickly and relatively inexpensive an elevation map can be generated through lowland tropical forest cover. The Caracol results are impressive as five days of flyovers collected data that "...far surpassed over two decades of on-the-ground mapping" (Chase et al., 2011:388). However, while architecture 25 cm in height was detected, cultural interpretations are still dependent on excavation and surface collection for the occupation of all the identified mounds to be attributed to the Late

Classic period (Chase et al., 2011:395). The pitfalls of interpreting remotely sensed data without ground truthing was first highlighted when Adams et al. (1981) used radar in the late 1970s to detect irrigation canals in Guatemala and suggest the widespread use of raised field agriculture among the Maya. Ground truthing of the purported canals revealed that they were not nearly as extensive as initially hoped (Pope and Dahlin, 1989). The lesson is that no matter how effective the mapping tool one uses, regional settlement studies remain dependent on traditional field work methods such as pedestrian survey, surface collection and ceramic cross-dating to infer population size and distribution.

Settlement studies have long been a basic form of data used by archaeologists working in Mesoamerica (and elsewhere) as the main way regional demographic patterns are generated for prehistoric peoples (Balkansky, 2006; Kanter, 2008; Kowalewski, 2008). In the highlands of Mexico, regional settlement patterns are generally recorded as the number of hectares of occupation by phase based on surface collection of ceramic sherds (e.g., Sanders et al., 1979; Kowalewski et al., 1989). The dry highland environment, with a relative lack of vegetation and extensive soil erosion, facilitates a survey methodology dependent on good visibility of ancient remains on the ground surface. In contrast, the mapping of individual mounds is the standard method used to document regional settlement patterns in Mesoamerica's tropical lowlands due to dense vegetation and obscuring ground cover (e.g., Ashmore,

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1981; Santley, 1990). In the Maya area, Prehispanic mounds have traditionally been mapped and counted within paths cut through the jungle that allow architecture to be seen; this is precisely the method used around Caracol before they employed lidar (Chase et al., 2011:389). The ability of lidar data to “see through” tropical vegetation and produce a fine-grained elevation map, that includes Prehispanic mounds, provides archaeologists with a powerful tool with which to explore occupation at a regional scale.

This paper presents the use of lidar data to locate 670 mounds in a 43.1 sq km area in the Soconusco region of southern Mexico (Fig. 1). Each documented mound was then visited and surface collected in order to determine the periods during which it was occupied as well as to establish the size of Izapa, the largest archaeological site in the region. The paper begins by contextualizing the collection of lidar data in terms of the goals of the Izapa Regional Settlement Project (IRSP) to document the regional history of the Izapa state (Guernsey, 2006; Lowe et al., 1982). Three and a half millennia of Prehispanic occupation from the piedmont zone around Izapa are then presented, based on the lidar data used to detect mounds and subsequent pedestrian survey to surface collect and date their occupation. Next, the effectiveness of lidar to detect mounds is presented and increased size estimates of the Izapa site are discussed. Finally, new architectural features, revealed by the lidar data, from the Izapa site core are presented. Results from the Izapa region demonstrate the potential of lidar to facilitate settlement survey by providing accurate base maps which are especially beneficial in lowland tropical environments with dense vegetation cover.

2. Background: settlement survey in the Soconusco region and the Izapa Regional Settlement Project (IRSP)

2.1. Previous settlement surveys in the Soconusco

Six previous systematic surface survey projects have been undertaken in the Soconusco. Each project focused on

documenting the estuary or coastal plain environments and defined sites based on the presence of mounds and/or the extents of surface scatters of artifacts. Northwest of Izapa, Barbara Voorhies and colleagues (2011) surveyed 44 sq km in the Acapetahua zone northwest of the Cantileña swamp and documented Archaic through Late Postclassic sites. Voorhies (1989:112) noted that due to the lack of surface plowing, often dense vegetation, and long occupation of the same areas, earlier sites are likely underrepresented. Voorhies and Kennett (1995) followed up on Voorhies' initial survey and walked the rivers between the towns of Pijijiapán and Mazatán to take advantage of rivers cutting their banks to expose sites buried by the extensive alluvium that has built. John Clark and Michael Blake undertook systematic survey in the Mazatán zone (Clark, 1994:96–9). Blake documented 51 sites in a 6 km stretch of estuary northwest of Puerto Madero and Clark undertook a 100% coverage, systematic survey of 50 sq km of coastal plain on the Ejido of Buenos Aires. In all, Clark (1994) documented 204 sites and the number of hectares of surface scatters of temporally diagnostic artifacts were recorded at each.

To the southeast of Izapa, Michael Love (2002:21–49) surveyed 200 sq km in the Naranjo River zone between the Suchiate River and the Guamuchal/Manchón swamp to put the site of La Blanca into regional context. Sites were defined based on the presence of mounds and all ceramic rims sherds, decorated body sherds, and figurines were collected. Mary Pye (1995:116–95) conducted a survey on the southeast side of the Guamuchal/Manchón swamp in the Jesus River drainage around the site of El Mesak. Mounds were documented and surface artifact scatters were also recorded, generally documented in cow pastures where trampled earth was cut by erosion providing a glimpse of subsurface remains (Pye, 1995:129).

Between Izapa and the Pacific Ocean, Rosenswig (2008) systematically surveyed a 28 sq km area of the coastal plain around the site of Cuauhtémoc (see Fig. 1). This survey provided a regional context for the Cuauhtémoc excavations (Rosenwig, 2010, 2012a) and took advantage of the correspondence of

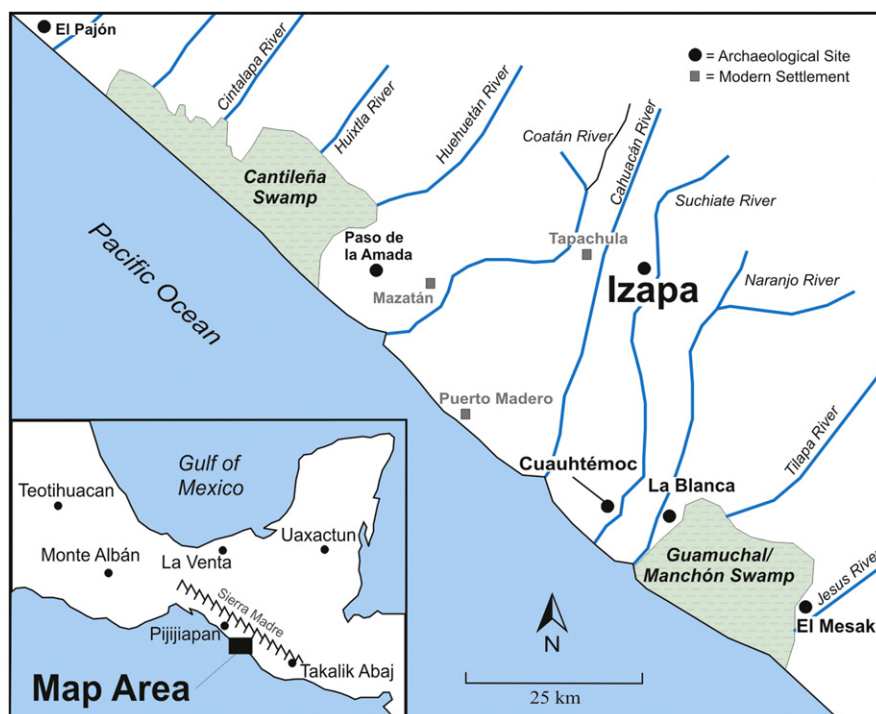


Fig. 1. Map of the Soconusco and sites mentioned in the text.

surface and subsurface remains produced through the trenching of drainage canals in an extensive system of banana plantations. The results presented in this article were generated from the next phase of Rosenswig's settlement project that extended the coastal plain survey to over 70 sq km and expanded the regional coverage to also include the low hills and piedmont environments (Fig. 2). Lidar data was also collected from ~50 sq km area of the low hills and pedestrian survey undertaken during the summer of 2012 – the results of which will be forthcoming. The survey of these three complimentary environmental zones between the Cahuacán and Suchiate Rivers provide insight into the settlement patterns from a variety of environments to explore the development of the Izapa state from a regional perspective. Recent work by Hector Neff in the estuary between the Cahuacán and Suchiate Rivers also employs lidar mapping to provide the first systematic survey of this environment. These data from the estuary will provide evidence from a fourth complimentary environmental zone.

2.2. Izapa

The site of Izapa was first excavated by Philip Drucker (1948) and later by the New World Archaeological Foundation (NWAf) in the 1960s (Lowe et al., 1982). NWAf investigations targeted the site's Formative period occupation and documented that Izapa was the most important Soconusco center during the Late Formative period (Lowe et al., 1982). However, the timing and manner that this rise to power occurred remains unknown. The nearby Cuauhtémoc survey (Rosenwig, 2007, 2008, 2009, 2012b) indicates a virtual abandonment of the coastal zone when construction began at Izapa during the Middle Formative period Duende phase

(850–750 cal. BC) (Ekholm, 1969; Lowe et al. n.d.). The initial construction at Izapa was therefore contemporary with the Gulf Coast Olmec center of La Venta and, at both sites, formal plazas were defined by monumental mounds (Lowe et al., 1982:127–9). In addition to Izapa, major Middle and Late Formative settlements on the Pacific coast of Guatemala were built at sites such as Takalik Abaj, Bilbao and Chocolá (Love, 2007:291–295). The construction of large sites on the Pacific Coast's piedmont during the second half of the Middle Formative period (750–350 cal. BC) marks a major settlement shift after the previous millennium when population centers were located on the coastal plain (Clark and Pye, 2000).

The Late Formative Guillén phase (350–100 cal. BC) is considered to be the apogee of the Izapa polity and a dozen plazas were created at the site by this time through the construction of platform mounds and temples, some reaching as high as 22 m (Lowe et al., 1982). These plazas were lined with stelae and altars, many of which contain complex narrative scenes and some of which legitimize rulership and/or conquest. These stelae define the so-called Izapan art style, which some have proposed to provide the “link” between Olmec and Classic Maya traditions of public art (Lowe et al., 1982:324–5; Pool, 2007:271–9 cf. Clark and Pye, 2000:243; Demarest, 2004:70). After the Late Formative period, the mounds of Izapa's central plazas (Groups A, B, C, D, E, G and H) were not augmented. The plaza called Group F (see Fig. 3) was built north of the Formative-period site core during the Classic period and a number of earlier stelae were reset in Late Classic period ballcourt (Lowe et al., 1982:307).

Due to the pervasiveness of the very distinctive San Juan plumbate ceramics, Drucker (1948:153–4) originally attributed Izapa's occupation to the Classic period. Lowe visited the site in the late 1950s and his recognition of the extensive Formative-period remains led to the NWAf's field work in the early 1960s. Lowe et al. (1982:307) describe Izapa as “a major regional community center...[that]...provided commercial and service functions as well as religious needs of a fairly large, relatively concentrated, group of people”. However, the main goal of the NWAf excavations “...was to determine the chronological and architectural relationships of the carved stone monuments” (Lowe et al., 1982:308). No research undertaken at Izapa was ever designed to investigate the regional settlement history of the area or the economic basis of this early state's power.

Michael Love (2007:291–2) and Arthur Demarest (2004:67) have both proposed that Izapa and other large sites along the coast of Guatemala were urban centers during the Late Formative period. In evolutionary terms, such urban centers were “...the paramount settlement of archaic states, or at the very least complex chiefdoms” (Love, 2007:292). In a chapter titled ‘The Origins of Maya States in the Late Preclassic’, Sharer and Traxler (2006:227) claim that “Izapa is a major center associated with the Isthmian tradition”. Likewise, Evans (2008:224) claims that “...it was during the Late Formative and Early Classic periods that Izapa achieved florescence as a regional capital.” Much is assumed about Izapa's population and political organization but in reality virtually nothing has been documented about these topics.

2.3. The Izapa Regional Settlement Project (IRSP) goals

The goal of the IRSP is to document regional settlement patterns and infer how the relative population levels in complementary environmental zones changed through time and how such changes correspond to the political organization at Izapa. In contrast to most regions of Mesoamerica where Classic period states are the primary focus of study, the Soconusco provides a case where the first thousand years of settled life (1900–850 cal. BC), at sites such as Paso de la Amada and La Blanca, are currently far better understood



Fig. 2. Three environmental zones surveyed by the Izapa Regional Settlement Project (IRSP).



Fig. 3. New World Archaeological Foundation map of Izapa (from [Lowe et al., 1982](#):inset) with Groups A, B and F indicated.

than the subsequent rise of the Izapa state. Despite the high-quality map of architecture at its core (Fig. 3), the full extent of Izapa was unknown before the IRSP documented them. Further, regional settlement patterns from the piedmont surrounding Izapa were also completely unknown from any time during the site's occupation.

The IRSP was designed as a pedestrian survey of three environmental zones: the coastal plain, the piedmont, and the intervening low hills (Fig. 2). As noted, the coastal plain survey is an amplification of a project Rosenswig (2010) began a decade ago that takes advantage of the canal system cut by large banana plantations to provide reliable estimates of the number of hectares of occupation for each Prehispanic phase. During the winter of 2011, the IRSP augmented this survey so that we now have 70 sq km of 100% coverage survey from this environmental zone with sites documented as the number of hectares over which temporally diagnostic artifacts were recorded (see Rosenswig, 2008). In the piedmont and low hills regions there is no disturbance to provide a systematic subsurface view of Prehispanic occupation with which to reconstruct the area over which settlement extended.

Lidar mapping was used to identify mounds in both the low hills and piedmont zones as these are the only consistently observable indications of past occupation visible on the ground surface. Such mapping was followed up with ground truthing of these remotely sensed data and pedestrian survey to collect temporally diagnostic artifacts from all identified mounds. While there are limits to the use of regional survey to estimate past population levels, especially in lowland Mesoamerica (Johnston, 2002), it is the only way to establish regional patterns in a systematic manner (Balkansky, 2006; Fish and Kawalewski, 1990; Banning, 2002:10–12). The use of lidar data to generate images of the mounds in the survey zone allowed for a much more efficient use of time than would be possible encountering new mounds in the traditional manner of lowland Mesoamerican pedestrian survey (Ashmore, 1981). During the spring and summer of 2011, we visited all identified mounds in a 43.1 sq km section of the Soconusco piedmont zone was surveyed and the results are presented in the remainder of this paper.

3. Methods: lidar and pedestrian surveys

Lidar data was collected by Airborne 1 Corporation, a private contractor based out of El Segundo, California. There were five flights which collected a total of 22 swaths of lidar data, each between 5 and 11 km long (see Inline Supplementary Fig. S1). Twenty of the flights, spaced about 350 m apart, were parallel to each other, and two were perpendicular to the rest. Fifteen flights were run from August 20–23, 2010 using an Optech ALTM 100K (A1) scanner. Due to a sensor error with certain flights beyond the 15 reported here, seven more flights were flown on April 29 and May 1, 2011 using a Reigl VQ 480 scanner. In each case, the scanner was mounted on a single engine Cessna airplane. Flying height was between 4000 and 4883 feet (1220 and 1488 m) with a ground speed of between 110 and 167 miles (176 and 267 km) per hour (Supplemental Table 1). These parameters are consistent with industry standards (Renslow, 2012:152) and comparable to the Caracol survey's flight elevation of 800 m and nominal ground speed of 288 km per hour (Chase et al., 2011:391). The use of two different sensors during two subsequent years does not appear to have adversely affected the lidar product delivered to us by Airborne 1 Corporation or the ability of the DEM hillshade it produced to detect archaeological mounds, as we detail in the rest of this paper.

Inline Supplementary Fig. S1 can be found online at <http://dx.doi.org/10.1016/j.jas.2012.10.034>.

The delivered lidar product render a nominal vertical accuracy of 18.5 cm ($\sim 0.6'$) at the 95% confidence interval (95% of points have the stated nominal vertical accuracy) and 15 cm ($\sim 0.5'$) at the 90% confidence interval. The nominal horizontal accuracy of is of 30 cm ($\sim 1.0'$), 1 sigma. The lidar campaign provided approximately 210 million lidar measurements, yielding an average total point density of 3.2 points per square meter which is consistent with industry standards (Doneus et al., 2008:884; Bollandas et al., 2012:2734) and ranged from 0.7 to 5.9 (see Inline Supplementary Fig. S2). Point cloud coordinates were processed to generate data in LAS format, in the WGS84 datum and UTM zone 15 projection.

Inline Supplementary Fig. S2 can be found online at <http://dx.doi.org/10.1016/j.jas.2012.10.034>.

Data were recorded at a higher density for the piedmont survey than for the low hills survey, to ensure enough ground would be detected, as the majority of the area to be mapped is planted in cacao orchards. Cacao production requires upper canopy vegetation to shade the cacao trees from direct sunlight and thus we originally assumed it was a more challenging vegetation cover to penetrate than, for example, the low hill zone, which is predominantly planted in corn and other crops grown in the sunlight. However, this upper canopy and cacao tree cover results in very little vegetation close to the ground surface that could obscure small changes in surface elevation such as low archaeological mounds (Doneus et al., 2008).

Lidar data were post-processed by Airborne 1 Corporation to filter out vegetation and above-ground structure points, yielding about 72 million “ground” elevation measurements. An average ground point density of 1.1 points per sq m (with a range between 0.9 and 2.3 – see Inline Supplementary Fig. S2) was achieved and this is similar to the average of 1.35 points per sq m reported from Caracol (Chase et al., 2011:391) which was used to generate their DEM hillshade images. There is no industry standard on what the point density that reaches the ground should be (Renslow, 2012:179–182) but the Caracol and Izapa results suggest that 1 point per sq m is sufficient to document Prehispanic mounds in the tropical lowlands of Mesoamerica. In a hypothetical case of a very small mound that only covers 3×3 m this would mean that nine points would define the mound and fourteen points would define the surrounding ground. Most mounds are in fact larger than this and so would be mapped with more points.

From these 72 million ground elevation measurements, raster products were created, including: a ‘bare earth’ Digital Elevation Model (DEM), hillshaded relief, normalized above ground surface as well as a lidar intensity signal – each with a cell size of 70 cm. Contours with a vertical interval of 0.5 m were also developed.

The IRSP piedmont survey zone is located on either side of the Izapa River between the Cahuacán and Suchiate Rivers (Fig. 4). Lidar data were collected beyond both of these rivers but the pedestrian survey zone was limited to the 43.1 km sq between them. The hillshade image of these data were used to identify and then visit and surface collect all documented Prehispanic mounds on the piedmont east of the modern city of Tapachula during the months of June and July 2011. A total of 670 mounds in the survey zone were visited and 13,759 ceramic sherds were collected and used to date the occupation of each mound (Table 1; Supplemental Table 2).

3.1. Hillshade depiction of lidar and mound identification

The lidar data allowed for a highly accurate digital elevation model (DEM) of the region to be created. This DEM was used to render a hillshade using ESRI's ArcGIS 9.2 software that served as the main “base map” throughout the summer 2011 field

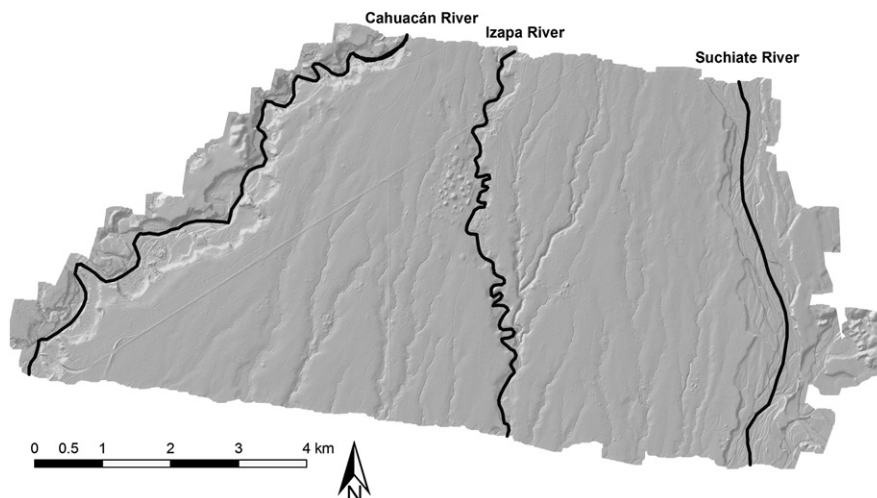


Fig. 4. Lidar-generated bare earth data used to generate a DEM hillshade of the IRSP piedmont survey zone.

season. These are orthorectified shaded relief images that can be used to measure linear distances between two points, as from a map. Various hillshades were created with the azimuth at different degrees. Comparing visual observation of the various hillshades to the mounds encountered in the field, we established that the most useful hillshade to identify small mounds was created when the azimuth was set at 315° (northwest), with altitude set at 45° and a Z-Factor of 1. These settings were employed to produce the hillshade images used to visually identify the mounds to be visited each day for ground truthing and surface collection. These settings were also used for the presentation of results in this paper. Although a contour layer was available (contour lines = 0.5 m) to overlay the hillshade, survey directors determined that the hillshade images made archaeological mounds more clearly visible and more accurately corresponded to the mounds recorded in the field. No single hillshade image will reveal all features on a landscape but circular features such as mounds should be visible from many angles.

3.1.1. The New World Archaeological Foundation's Izapa map

The published Izapa site map (Fig. 3) was used to evaluate how accurately the DEM and hillshade images rendered mounds. The NWAf map was scanned, geo-referenced, and inserted as a layer in the project's GIS database. Once the map was geo-referenced, location points were added to all of the 161 mounds reported by Lowe et al. (1982:inset). These points were coded to reflect the following information: 1) x, y, and z coordinates, 2) mound number from the NWAf map, and 3) whether or not they were visible on the DEM hillshade or 0.5 m contour lines.

3.1.2. Hillshade depiction of mounds

Known mounds from the NWAf map were traced in ArcGIS on the DEM and their heights defined. Based on these measurements, two algorithms were created and applied to the entire 43.1 km sq survey area. Both algorithms were employed to locate mounds on the map using ArcGIS 10.0's "select by attribute" using an SQL query using the 50 cm topographic rendering of the lidar DEM. Elevation and contour length were employed to identify mounds, based on the idea that mounds are discrete, raised areas. The first algorithm selected contour lines that were less than 450 m long with an elevation greater than 200 masl. This resulted in thousands of non-mounds being selected. A

second algorithm was applied that limited contour length to between 50 m and 450 m and elevation greater than 200 m. This second attempt left many mounds (clearly visible on the hillshade) unidentified because they did not have contour lines that closed around them. This was especially the case for mounds that were located on moderate to steep slopes. Both of these queries easily identified medium and large mounds but small mounds (smaller than 1 m in height) were difficult to identify (Fig. 5). For these small mounds, we determined that slope rather than height was the determining factor to recognize mounds on the hillshade projection of the region. However, in all cases, visual inspection of the DEM hillshade allowed for accurate identification of mounds. There is a lot of potential work that remains to be done on these DEM data that will likely reveal more architectural features with visualization techniques currently being proposed (e.g., Challis et al., 2011; Kokalj et al., 2011; Stular et al., 2012). However, our first attempt at projecting the microtopography of the area and the identification of Prehispanic mounds provides such amazing regional data that we will spend a long time exploring the substantive archaeological contribution of these data before we are likely to finesse more information from them.

3.1.3. IRSP hillshade DEM of the Izapa site core

The previously known Izapa mounds were added as a point layer to the project GIS database, in the manner described above. These location points were displayed in red if they were visible in the DEM hillshade or the 0.5 m contour data and in yellow if they were originally mapped by the NWAf but not visible on our DEM. Mounds mapped by the NWAf but not visible on the DEM were visited by crew members to evaluate why the mounds were not visible on our rendition of the lidar data. Such mounds were very small (i.e., less than 0.5 m) and either obscured by vegetation or, more frequently, had been leveled since they were mapped in the early 1960s. However, even in cases where mounds had been destroyed, surface collections were taken from the remaining artifacts on the ground surface.

3.1.4. Archaeological mound identification

The survey crew members experimented with the hillshade image during the first week of field work in the area north of Izapa Group F. Mounds were identified using both the hillshade (at various azimuths) and 0.5 m topographic renderings of the DEM

Table 1

Mounds documented by the IRSP on the Soconusco piedmont by time period.

Period	Cal Years B.C./A.D.	Phase	# of Mounds with Occupation
Late PC	1500	Late PC	5
Early Postclassic	1350	Remanso	102
Late Classic	1000	Peistal	141
	700	Metapa	
Early Classic	600	Loros	129
	500	Kato	
	400	Jaritas	
	200	Istapa	
Late Formative	100 B.C./A.D.	Hato	96
	100	Guillen	
Middle Formative	350	Frontera	189
	550	Escalon	
	750	Duende	
	850	Conchas	
Early Formative	1000	Jocotal	7
	1200	Cuadros	
	1300	Cherla	
	1400	Ocos	
	1500	Locona	
	1700	Barra	
	1900		

information. “Potential mounds” were identified with blue points and labeled with their x,y coordinates to facilitate finding them in the field. The labels served to both uniquely identify potential mounds and as a spatial guide to where the mound was located. The x and y coordinates were entered into our Garmin 60CSx GPS devices and used to provide directions to each potential mound. Potential mounds that were confirmed to be actual archaeological mounds (based on a distinct raised area associated with ceramic sherds) were then labeled with a mound number. Any “potential mound” that was determined not to have been an archaeological feature was labeled as a “ground truth” point – GPS coordinates were recorded and entered in a ground truth log. The area of confirmed mounds and ground truth points were photographed and, in the latter case, the reason for our misidentification as a mound was sought.

Ground truth points where no archaeological remains were located were deleted from the list of “potential mounds”. During the first week of field work we quickly began to understand how different features in the landscape appeared on the DEM, hillshade, and 0.5 cm contours. Rosenswig then reviewed the entire hillshade image systematically and created a list of “potential mound” points over the 43.1 km sq piedmont survey area between the Suchiate and Cahuacán Rivers. Maps were printed out with an area to be surveyed that included labeled potential mounds points overlaid on the hillshade. We determined that mounds higher than 0.5 m could reliably be located regardless of vegetation cover, even when modern houses were built atop them. As the field season progressed, less error was presented in identifying potential mounds, and smaller anomalies were no longer visited.

3.2. Pedestrian survey methodology

3.2.1. Locating archaeological mounds

Each day, survey teams employed a hillshade image of the region they planned to investigate with all potential mounds indicated. Hillshade images were printed in color with the GPS coordinates of the potential mounds (as described above). These GPS coordinates were entered into the Garmin 60CSx units. Properties were only entered when permission was given by the landowners or proxy permission was given by family members. This meant that some areas had to be visited more than once before permission could be obtained to enter the property. In a few rare cases ($n = 8$ of 670 mounds), permission to enter the property was denied. Notes were taken describing the encounter and these mounds were labeled as potential sites that we could not confirm due to lack of permission. In the vast majority of cases, permission was granted to enter the land and survey members used the GPS units to locate the potential mound. In only eleven instances, mounds representing archaeological sites were discovered where no potential mound was identified on the DEM hillshade. These were always small mounds (less than 0.5 m in height): five of which were on the edges of roads or streams and the other six were in sections of the lidar where low ground cover created a “rough” area of the hillshade that obscured these low mounds from being visually identified. When encountered, mounds not identified on the hillshade image were recorded and artifacts were collected in the same manner as targeted mounds. The rarity of mounds we missed identifying ($n = 11$ of 670 in a 43.1 sq km area), and the fact that none were higher than 0.5 m, reassured us of the effectiveness of our ability to visually recognize mounds from the hillshade images.

3.2.2. Recording archaeological mounds

If the ‘potential mound’ under investigation was determined to represent an archaeological mound, it was given a site number. To

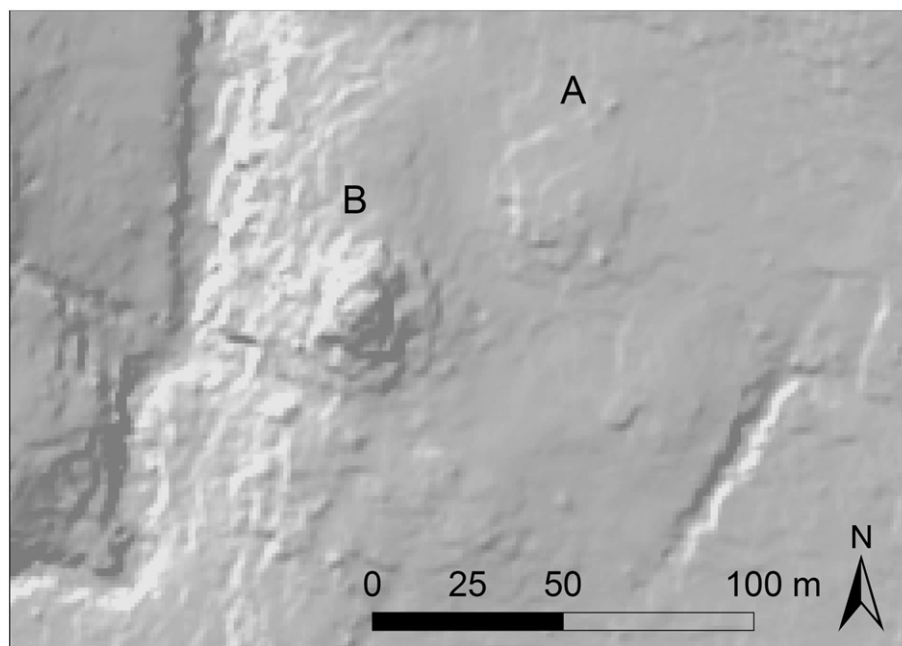


Fig. 5. Two potential mounds labeled A and B. Potential mound A is hard to identify visually on a hillshade image because its slope >1 . Potential mound B is clearly defined (slope ≤ 1) and its designation as a mound is thus more secure.

avoid the duplication of site numbers one survey team would assign odd numbers, while the other was assigned even numbers. Daily communication between survey teams ensured that any gaps in the sequence would be filled. A site form was filled out for each mound and its relationship to other mounds nearby (if any) was noted. Date, survey directors, landowner name, number of collection contexts, and number of mounds were recorded on every form. Descriptions of the environmental conditions, soil, vegetation, and ground visibility were also recorded on each site form. A sketch map of the site was drawn to record distinctive features in the vicinity of the site (roads, houses, fences, other mounds, etc.) to aid in the future location of the site and provide information that would be pertinent for the consideration of future excavations.

GPS coordinates were recorded in order to confirm the location of each mound. Coordinates were also recorded of any nearby locations where archaeological materials were collected (see below). The GPS coordinates for each mound, and associated surface collection areas, were recorded on the back of the site form as backup in the event of technical difficulties. Mounds were always photographed, often from a number of angles and distances. For each photograph, we recorded a description of the subject, the direction the camera was facing in degrees from north, degrees from horizon (i.e. camera tilt), distance from the object being photographed, and the camera height at the time of the photograph. All of this information was recorded in field notebooks as well as on the site forms.

3.2.3. Surface collecting archaeological mounds

Prehispanic artifacts were collected from the surface of each mound. Workmen and survey directors would walk across the mound, and the area a small distance surrounding the mound (usually within 5 m), looking for temporally diagnostic artifacts such as ceramic sherds and figurine fragments. At most mounds ceramic sherds were abundant. In such cases, remains most likely to be diagnostic, like rims sherds and those with decoration or with well-preserved slip, were collected. At mounds where surface remains were less abundant, seemingly non-diagnostic body

sherds were also collected, in the hope that temporally diagnostic features could be identified once they were cleaned. Figurines were rarely encountered, but were included in the collection when they were found.

When surface conditions did not allow us to locate artifacts (e.g., thick grass cover), survey directors also targeted nearby areas where artifacts were more abundant due to erosional features or human disturbance. The designation “Context 1” was always reserved for the mound itself, whether or not archaeological remains were collected. Additional collection contexts were, therefore, given designated Context 2, Context 3, etc. (see [Supplemental Table 2](#) for a complete list of mounds and collection contexts). The GPS coordinates for each collection context was recorded (labeled, for example, Tp2000C2) in the Garmin 60CSx units and also logged on the back of site forms. Where streams or other linear features produced artifacts that we collected, GPS coordinates were recorded at either end of the collection area (labeled, for example, Tp2000C2-1 and Tp2000C2-2). Photographs were taken of all collection contexts and were recorded in the manner described above. The collection of artifacts from these nearby disturbance features was a pragmatic strategy to maximize the chance of fully documenting the occupation history of mounds with few artifacts visible on the ground surface.

3.2.4. Labeling archaeological mounds

3.2.4.1. Iz mounds. “Iz” mounds (short for Izapa) were considered part of the site of Izapa. The first 161 mounds were recorded by the NWAf ([Lowe et al., 1982](#)) and during the 2011 survey season we continued numbering mounds starting with Iz 162. Mounds were designated as Iz mounds if they fell within the area determined by Rosenswig as forming a continuous concentration of mounds surrounding the site’s monumental core. The area of mounds designated “Iz” extended over an area measuring roughly 3.3 km in diameter. Rosenswig used visual inspection of the hillshade image to preliminarily determine Izapa’s limits in the field. Ongoing analysis of when mounds were occupied and their spatial relationship will provide more formal definitions of the Izapa site’s

limits and how this changed over time. The original 161 mounds mapped from by the NWAF were located and surface collected in the course of the 2011 season, as were 138 new mounds (Iz 162 – Iz 299) beyond the limits of the NWAF survey (Supplemental Table 2).

3.2.4.2. Tp mounds. Designating mounds as “Tp” (short for Tapa-chula) was a continuation of the numbering system established by Rosenswig (2008) during his Soconusco Formative Project (SFP). The numbering of Tp sites continued with the first season of the Izapa Regional Survey Project (IRSP) during the summer of 2011, with the last SFP site as Tp 90 (Rosenwig, 2008) and the first IRSP site beginning with Tp 91 (Rosenwig et al., 2012). In order to differentiate between sites in different environmental zones, Tp site numbers for the piedmont zone began with Tp 2000. The number 2000 was selected because the coastal plain zone began with Tp 1 and the Tp 1000 series of numbers was reserved for the intervening low hills zone. Tp numbers were given to any mounds documented beyond the Iz mounds on the piedmont. In all, we identified and visited 371 Tp mounds in the piedmont survey zone.

3.2.4.3. GTruth points. “GTruth” (short for ground truth) points were the designation given to areas visited where a mound was suspected from the lidar imagery, but no archaeological site was found. As this information is potentially valuable for refining our interpretation of the lidar imagery, GPS points and photographs were taken at the location where the mound had been suspected. GTruth GPS coordinates were coded on the GIS map as purple so that it was clear that the potential sites had been visited, but were not archaeological sites. The number of GTruth points decreased dramatically as the season progressed, because we became more adept at reading the DEM hillshade projection for mounds. This is reflected in a greater concentration of GTruth points to the northwest of Izapa’s Group F, where we began our survey.

3.3. Post-pedestrian survey analysis

3.3.1. GPS data download

GPS data were backed up weekly in the field laboratory and double-checked for errors. At this time surveyed areas were also checked for completeness. The GPS data were organized into an Excel file and separated into spreadsheets according to point type (i.e. Tp points, Iz points and GTruth points). The data were then loaded into the project GIS database and checked for errors visually once overlain on the DEM hillshade imagery.

3.3.2. Ceramic analysis

Initial temporal analysis of ceramic sherds collect from survey was undertaken simultaneously with field work. All ceramics sherds were washed and separated into rims, other distinctive sherds (such as bases, supports, those containing distinctive decoration) and plain body sherds and then counted according to these three categories (Supplemental Table 2). Each collection context was laid out on tables for analysis and temporal designations were made by Rosenswig. Of the 670 mounds (371 Tp mounds and 299 Iz mounds), temporal associations were achieved at 363 of them. Although all artifacts that were present at a mound were collected, and all collected artifacts were examined, only 363 were designated to one or more periods of occupation. This means that for 307 mounds (i.e., 670–363) there are no temporal designations. These 307 mounds with no temporal designations (which include the eight where permission was denied) make true demographic reconstructions problematic, but such is the nature of all surface survey of undisturbed architectural mounds.

The ceramic analysis, and resulting inferences about changing settlement patterns, is therefore dependent on the accuracy of

Rosenwig’s identifications. These are better for the Formative phases than for the Classic period phases. The 2011 analysis divided sherds into 15 temporal periods (similar to Rosenswig, 2008) but in order to avoid changes caused by future analysis, results are presented here as seven macro-temporal periods (Table 1 and Fig. 6) as the main point of this paper is to present the successful use of lidar mapping at Izapa. All ceramics are curated for future reanalysis that will refine the temporal designations. In particular, a phase by phase analysis of the size and shape of Izapa during the Middle and Late Formative periods is crucial to understanding the organization of the Izapa state.

3.3.3. Linking field and laboratory data in Microsoft Access database

Following data entry into Excel, each context was given an identification number that matched the GPS field provenience number recorded by the GPS devices in the field exactly. This name served as the primary key in all following actions in the database. A Microsoft Access database was created so that the field GPS data could be joined with the laboratory ceramic qualitative and quantitative analysis data. These data were linked using the unique GPS field provenience numbers. Output data were then uploaded into the project GIS database. All points included on the map now contain ceramic and GPS field data.

3.3.4. Photo entry in GeoSetter

Due to the poor visibility of photo boards in photographs of mounds, we elected not to use them. Without such a written description of the subject, many of the photographs of low mounds in cacao orchards look the same. As a result, we entered photo log data and GPS coordinates directly into the photograph as metadata in a freeware program called GeoSetter created by Friedman Schmidt. File names were not changed, as they had been referenced in other locations, such as the GTruth log. Instead, data and description location entered can be accessed from the metadata of each photograph.

Data were entered for at least one photograph for each site or GTruth. Under the location tab GPS points were entered in decimal degrees for the object that was the subject of the photograph, as opposed to the camera position. We also entered more general data about the country, state, city, and sublocation about the photo. Under the source/description tab, we included the initials of the individual that took the photograph and the individual that entered the data into the program (under “caption writer”). The object name was, in most cases, the site or GTruth number and the name

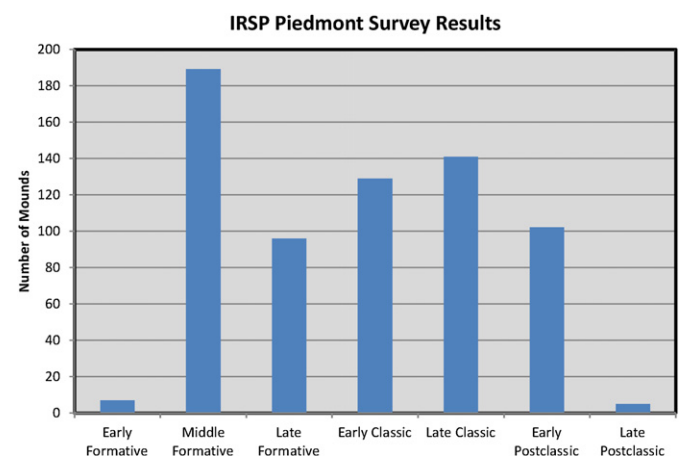


Fig. 6. Number of mounds documented in the 43.1 sq km survey of the piedmont with surface-collected remains from each temporal period.

of the landowner was entered as the “headline” whenever possible. The caption included a brief description of the content of the photograph as well as the direction of the photograph in degrees from north, camera tilt in degrees from horizon, the distance from the object being photographed, and the camera height above ground surface.

4. Results

4.1. Preliminary diachronic settlement patterns from the Soconusco piedmont

The IRSP survey of the Soconusco piedmont zone around Izapa is the first regional settlement project to target Prehispanic settlement patterns from this geographical zone. As such, there are no direct comparisons to be made with previous results from other parts of the Soconusco (but see Love, 2007 for a discussion of the Guatemalan coast). Diachronic results are presented in Table 1 and Fig. 6 as the number of mounds from which temporally diagnostic artifacts have been identified. These initial summary results are based solely on the temporal designations of surface-collected ceramics from 2011 and presented in macro-temporal periods that span many centuries as analysis is still ongoing (discussed above).

The results of mound occupation from the NWAf excavations at the site of Izapa (Ekholm, 1969; Lowe et al., 1982) do not directly contribute to the settlement patterns presented here. However, our systematic surface collections from mounds that define the Izapa site center are consistent with excavations at the site. The NWAf work in the 1960s documented mound building in the southern Groups A, B, C, D, E, G and H exclusively from the Middle and Late Formative periods and Classic period construction exclusively from Group F (Lowe et al., 1982). This is what we documented from the surface remains as well. Further, all Early Formative (1900–850 cal. BC) ceramics documented by the NWAf were from the mound 30 complex that defines the north side of Group B (Lowe et al. n.d.). The only Early Formative surface remains we recovered (1 sherd from the Locona phase and 2 from the Jocotal phase) were also in the immediate vicinity of Group B.

The preliminary quantitative results of mound occupation based on surface remains depict peaks in the Middle Formative and Late Classic periods (Fig. 6) which correspond to both the time of initial coalescence as well as the subsequent reorganization of the Izapa polity. Past occupation was certainly not limited to mounds but in the heavily vegetated lowland environment they are the most obvious evidence of Prehispanic occupation. The “mound counting” methodology traditionally employed by survey project in the Mesoamerican lowlands can make direct population estimates problematic (Johnston, 2004; Pyburn, 1989:1–4). Earlier period remains should have a tendency to be more deeply buried and so underrepresented. In addition, periods during which mounds were either not built or less frequently built can be expected to also be underrepresented when counting mounds is the basis of documenting settlement patterns. Less mound building likely accounts for why few mounds were documented during the Early Formative (see Rosenswig, 2012b) and Late Postclassic periods. However, Middle Formative through Early Postclassic occupation clearly do not indicate greater occupation of mounds the more recently they were occupied. Therefore, our preliminary results reflect, to some degree, the relative number of people inhabiting the survey zone at different times in the past.

Quantitative results of the total number of mounds with occupation documented during each time period are more meaningfully understood in the context of changing spatial patterns, which we have also documented. Analysis is ongoing

and, due to lack of space, only one example is presented from the Late Formative to Early Classic to Late Classic period occupation. Mounds occupied during the Late Formative period – for which the site is best known – were concentrated at Izapa’s southern monumental core (Fig. 7a), whereas during the Early Classic period occupied mounds were more dispersed across the survey zone (Fig. 7b) and the overall number of occupied mounds increased (Fig. 6). Furthermore, the majority of mounds at the southern site core were abandoned during the Early Classic period and several new mounds occupied at the northern site center named Group F (see Fig. 7b). Despite the lack of Early Classic period ceramic remains recovered from the southern center, 33 caches from this period were documented by NWAf excavations (Lowe et al., 1982:308). Therefore, the southern core

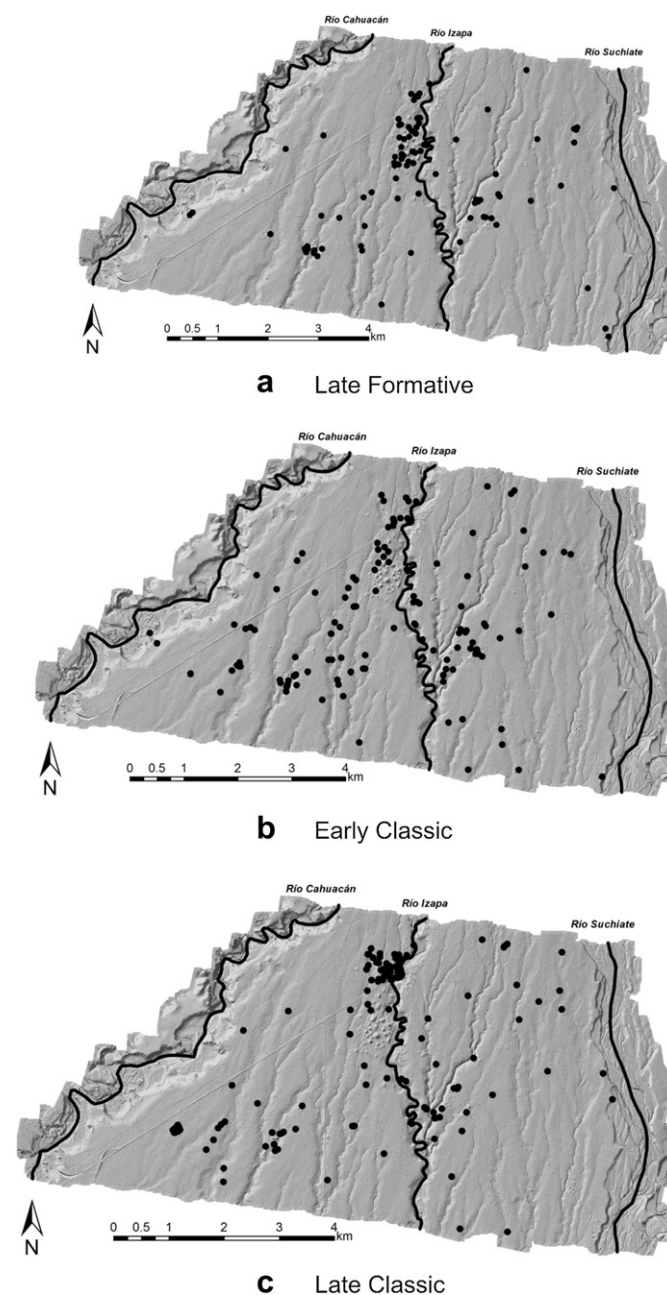


Fig. 7. Spatial distribution of mounds occupied during the Late Formative (a), Early Classic (b) and Late Classic (c) periods.

was not occupied intensively enough to leave sherds to be recovered by our survey (or by the NWAf in their excavations of mound fill). Instead, because numerous caches were interred, this zone is reasonably interpreted as changing from a residential to a ceremonial precinct. The southern center of Izapa should be considered the “old part of town” during the subsequent Classic-period occupation of the site when construction focused at Group F.

The change in the spatial distribution of occupation from the Late Formative to Early Classic period suggests that a disruption of the Izapa polity occurred at this time, resulting in the abandonment of traditional seats of power. Recent geological analysis indicates that the Izapa River was blocked due to an eruption of the Tacaná volcano at AD 25–75 during the proto-Classic period (Macías et al., 2000). The Mixcun Flow deposit covered most of the area between the Cahuacán and Suchiate Rivers and the flow itself stopped only a kilometer north of the Izapa site (Macías et al., 2000: Fig. 1). So, while Izapa was not damaged by this lava flow, nearby vegetation would have been destroyed and river patterns disrupted. The correspondence of settlement change and volcanic activity suggests that the local environment played a role in the political disruption at the end of the Late Formative period.

During the Late Classic period, the distribution of occupied mounds documented within the IRSP piedmont survey region then seems to have further concentrated at Group F, the northern monumental core (Fig. 7c). The total number of mounds where we have documented occupation within the survey zone at this time ($n = 141$) increased slightly from the Early Classic period (Table 1, Fig. 6) and a greater proportion of those mounds are clustered

around Group F (compare Fig. 7b to c). As with the Early Classic period, caches continued to be interred in the “old part” of Izapa during the Late Classic period, but virtually no other occupation is documented in the southern core by our survey or by the NWAf excavations. The plumbate ceramics produced during the Late Classic period are very distinctive and extremely durable, so their absence on the surface of mounds in Groups A, B, C, D, E, G and H suggests a very real lack of domestic occupation. Further, as numerous Late Formative period stelae were removed from the southern center of Izapa and reset in the Late Classic period ball-court in Group F, symbolic ties to the old part of the city were further reinforced.

4.2. Larger estimates of Izapa's size

Many new mounds were documented by the IRSP right around the previously mapped center of Izapa. For example, on high ground east of the Izapa River a group consisting of 11 mounds is visible directly across from Group G (Fig. 8). Based on temporal analysis, these mounds were occupied during the Middle and Late Formative periods, so they were part of the Formative-period polity when Izapa was at its apogee. These 11 new mounds (as well as the five others visible from the hillshade depiction of the area presented in Fig. 8) were simply never documented because the NWAf mapping effort was confined to the west side of the river (see Fig. 3).

A second example of the expanded extents of the Formative-period site of Izapa is evident south and west of Group E (Fig. 9). Another 20 new mounds are clearly visible beyond the edge of those mapped by the NWAf (Fig. 3). Some mounds, like Iz 201, Iz

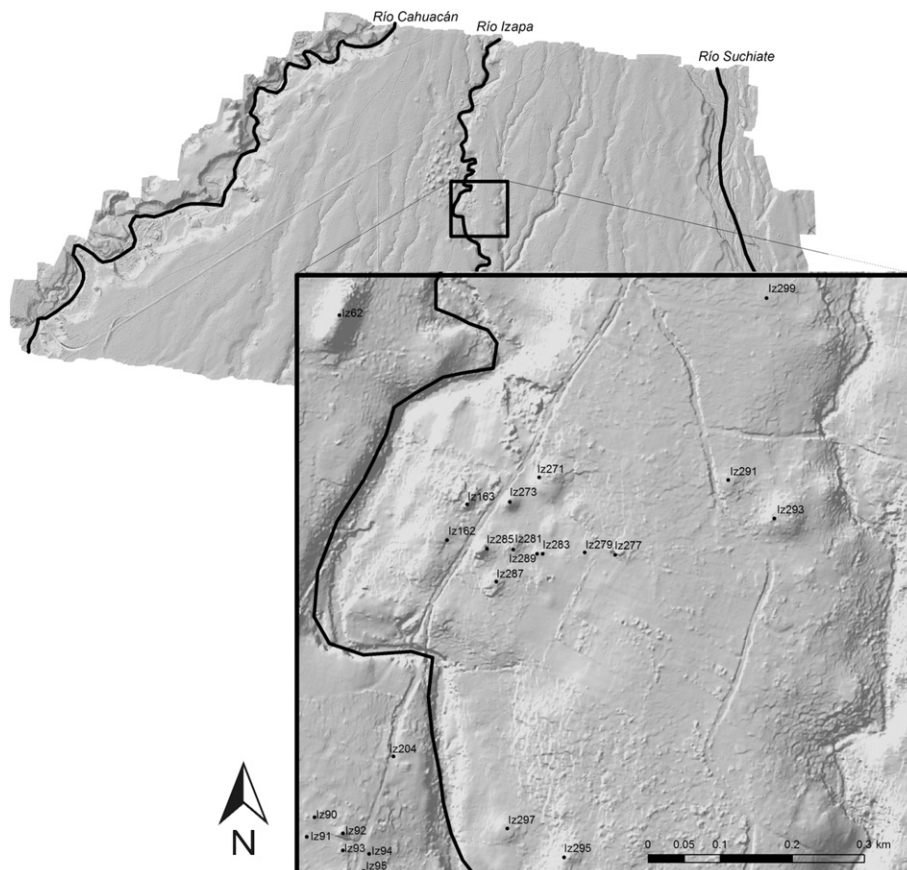


Fig. 8. Newly documented Formative-period mounds east of the Izapa River.

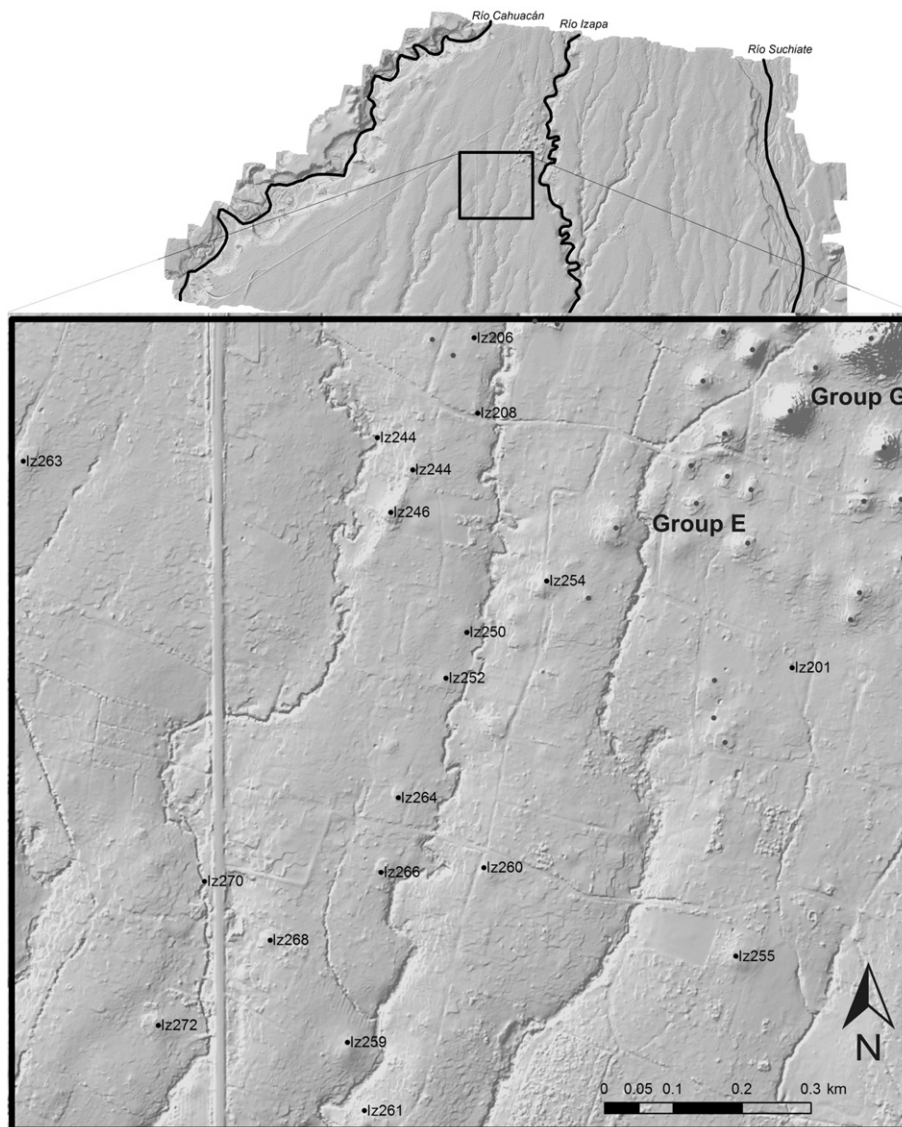


Fig. 9. Newly documented Formative-period mounds southwest of Izapa's Group A and Group E.

206 and Iz 208 were small and apparently missed by the NWAf mappers (see Fig. 9). However, the rest of the mounds documented in the south and west parts of the site were simply beyond the limits of the area mapped in the 1960s. The new Izapa mounds visible in Fig. 9 are in the blank area of the NWAf map to the left of the north arrow (see Fig. 3). Most of the mounds in this zone are located on small streams that the lidar documents and hillshade imagery does a wonderful job of depicting. In all, we have approximately doubled the areal extents of the Formative-period occupation of Izapa as well as mapped the site's immediate sustaining area. Due to their small size, we presume that these new mounds served domestic functions. Once the more fine-grained temporal analysis of ceramics is completed, the IRSP will produce the first detailed estimates of the actual size of the Izapa center and how this changed on a phase by phase basis during the course of the Formative period.

Changes to our understanding of the Classic-period occupation of Izapa are equally significant. The size of the Izapa polity during the Late Classic period was approximately three times as large as previously documented. New size estimates are based on the

extents of the domestic mounds that extend out from Group F. For example, Fig. 10 shows previously documented mounds as unnumbered dots whereas all those with Iz numbers were documented in 2011. A notable characteristic of Group F and surrounding occupation is that the area is located on a plateau that raises Late Classic and Early Postclassic occupation approximately 10 m above the Izapa River. So, while the initial Early Classic period impetus to relocate the site center may have been due to a natural disaster, the new occupation would have also been much more defensible.

4.3. New architectural features documented at Izapa's monumental core

The lidar mapping of the Formative-period center of Izapa also reveals a number of new features (Fig. 11a). The three most obvious that we have documented at this point are, first, that the platform below Mound 30 is rectangular (rather than square), and so, is larger than mapped by the NWAf. Second, that DEM hillshade provides more detail of the Izapa River, including a formal plaza by the river as well as some clear terraces. And third, a possible E-

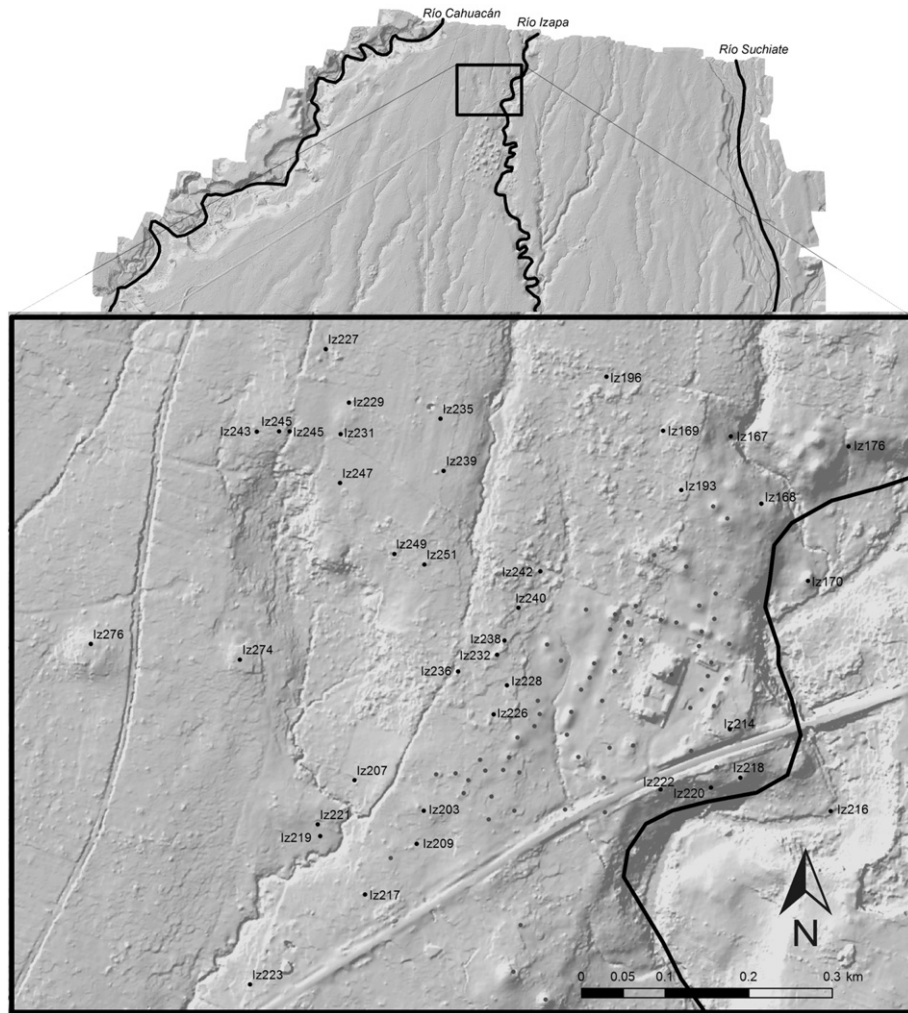


Fig. 10. Newly documented Classic-period mounds around Izapa's Group F.

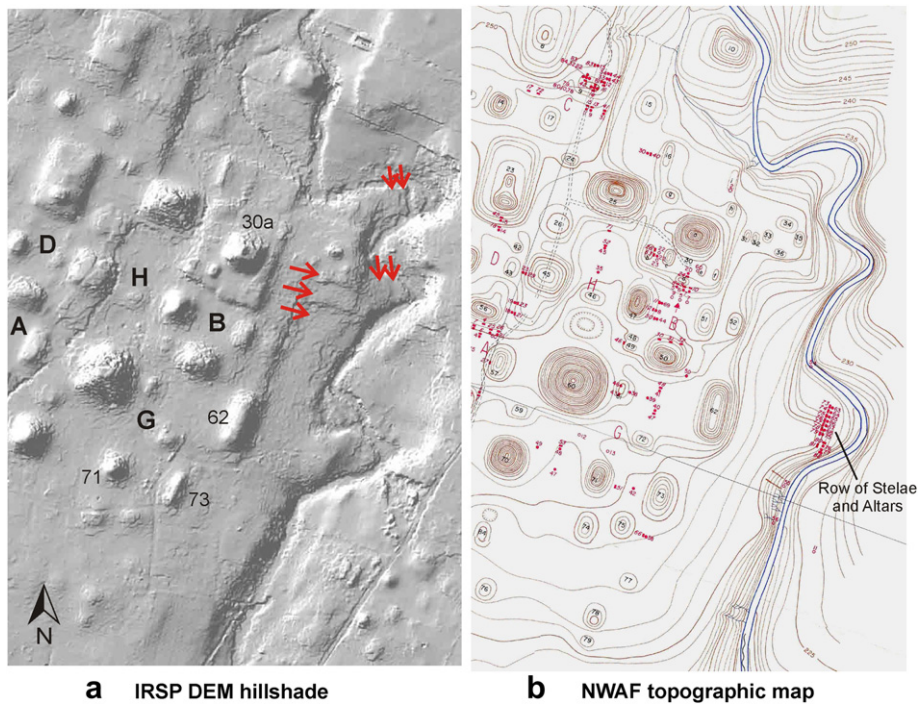


Fig. 11. DEM hillshade depiction (a) with red arrows indicating terraces and the original NWAf topographic map (b) of Izapa's Formative-period center with the row of stela and alters indicated. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Group at the south end of the site revealed by the newly defined shape of Mounds 71 and 73.

The platform on which the Mound 30 complex sits is actually rectangular and larger than the way it was depicted on the NWAF map (Fig. 11b). The ceramics recovered from the excavations of Mound 30a are what the Izapa Formative period chronology is based upon (Ekholm, 1969). Mound 30a was the first mound built at Izapa and the NWAF excavations revealed that the initial construction dates to the early Middle Formative Duende phase (850–750 cal. BC) and that the platform was later built up around it (Lowe et al. n.d.). Mound 30a and the underlying platform reached their current extents by the Late Formative period Guillén phase (350–100 cal. BC) and the DEM hillshade reveal that the platform was considerably larger, with sharper corners and straighter sides than depicted by the NWAF map. Mound 30a thus ended up sitting on a platform that was larger and more formally built than could be inferred from the NWAF topographic map.

Directly east of Mound 30a and Group B, the DEM hillshade depicts formal terraces leading down to the Izapa River (see arrows on Fig. 11a) that were not mapped by the NWAF. These terraces indicate more formal access to the river from the Formative-period site core. The DEM hillshade also reveals a more formal plaza east of Group B and Mound 62 directly above the Izapa River. This plaza is also the location of a row of 10 stelae and 9 altars (indicated on Fig. 11b) on a raised bend in the Izapa River. These lidar data allow us to interpret this topography as a formally constructed plaza down by the water rather than simply the bank of the Izapa River. Careful comparisons of the two maps make it evident that the NWAF placed considerably more attention on mapping mounds and that the Izapa River received a less detailed treatment. This is understandable as the mounds and stelae were the focus of NWAF investigations rather than a regional topographic map. This highlights that the major advantage of lidar-generated DEMs over conventional mapping by archaeologists is that, due to the objectivity of laser scanning across a large area, new features can be revealed that were not noticed on the ground (Doneus et al., 2008:890).

Another rather surprising finding, given the generally accurate depiction of mounds by the NWAF, is that there appears to be an E-Group at south end of site. First defined at Uaxactún in Guatemala (Blom, 1924), E-Groups are identified as a pair of pyramids – a conical one to the west and a long, linear one to the east – that together are located south of the earliest principal mound of a site. This inference of an E-Group at Izapa is based on the shape of Mound 71 and Mound 73 as documented by the lidar data. On the NWAF map these mounds are both vaguely oval (Fig. 11b) whereas the DEM hillshade clearly depicts Mound 71 as round and Mound 73 as long and thin (Fig. 11a). An E-Group is thought to have served an astrological function and was a feature of many Middle and Late Formative sites (e.g., Aimers and Rice, 2006; Clark and Hansen, 2001). In contrast to the way Mound 71 and 73 were mapped by the NWAF, our new hillshade depicts them in precisely the shape and orientation expected for an E-Group. Furthermore, Mounds 71 and 73 are located along the site's orientation (20° east of north) directly to the south of Mound 30a, the first pyramid built at the site.

5. Summary and conclusion

A few days of lidar mapping and two months of pedestrian survey have allowed us to reconstruct settlement patterns in a 43.1 sq km area around the site of Izapa. In addition, the lidar-generated DEM has allowed us to determine the full extents of the Izapa site, and, in conjunction with the temporal data provided by our pedestrian survey has approximately doubled the size of the

Formative period occupation and tripled the size of the site from the Late Classic period. Furthermore, the DEM hillshade image has revealed numerous new features from within the monumental core of Izapa itself, including the full size and shape of the platforms under the Mound 30 complex, square terraces between the ceremonial core of the site and the Izapa River, and a potential E-Group in the southern zone of the site core. Lidar technology has allowed each of these substantive contributions to our understanding of the Izapa state to be achieved in an extremely cost-effective manner and with a greater degree of precision than with any other existing mapping technology.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at <http://dx.doi.org/10.1016/j.jas.2012.10.034>.

References

- Adams, Richard E.W., Brown Jr., W.E., Patrick Culbert, T., 1981. Radar mapping, archeology, and ancient Maya land use. *Science* 213, 1457–1468.
- Aimers, James J., Rice, Prudence M., 2006. Astronomy, ritual, and the interpretation of Maya “E-Group” architectural assemblages. *Ancient Mesoamerica* 17, 79–96.
- Ashmore, Wendy, 1981. Some issues of method and theory in lowland Maya settlement archaeology. In: Ashmore, W. (Ed.), *Lowland Maya Settlement Patterns*. University of New Mexico Press, Albuquerque, pp. 37–69.
- Balkansky, Andrew K., 2006. Surveys and Mesoamerican archaeology: the emerging macroregional paradigm. *Journal of Archaeological Research* 14, 53–95.
- Banning, Edward B., 2002. *Archaeological Survey*. Kluwer Academic/Plenum Publishers, New York.
- Blom, Frans, 1924. Report on the Preliminary Work at Uaxactun, vol. 23. Carnegie Institution of Washington Yearbook, Guatemala. 217–219.
- Bollandsås, O.M., Risbøl, O., Ene, L.T., Nesbakken, A., Gobakken, T., Næsset, E., 2012. Using airborne small-footprint laser scanner data for detection of cultural remains in forests: an experimental study of the effects of pulse density and DTM smoothing. *Journal of Archaeological Science* 39, 2733–2743.
- Challis, Keith, Carey, Chris, Kinsey, Mark, Howard, Andy J., 2011. Airborne lidar intensity and geospatial archaeological prospection in river valley floors. *Archaeological Prospection* 18, 1–13.
- Chase, Arlen F., Chase, Diane Z., Fisher, Christopher T., Leisz, Stephen L., Weishampel, John F., 2012. Geospatial revolution and remote sensing LiDAR in Mesoamerican archaeology. *Proceedings of the National Academy of Science* 109, 12916–12921.
- Chase, Arlen F., Chase, Diane Z., Weishampel, John F., Drake, Jason B., Shrestha, Ramesh L., Clint Slatton, K., Awe, Jaime J., Carter, William E., 2011. Airborne LiDAR, archaeology, and the ancient Maya landscape at Caracol, Belize. *Journal of Archaeological Science* 38, 387–398.
- Clark, John E., 1994. The Development of Early Formative Rank Societies in the Soconusco, Chiapas, Mexico. Unpublished Ph.D. dissertation, University of Michigan, Ann Arbor.
- Clark, John E., Hansen, Richard D., 2001. The architecture of early kingship: comparative perspectives on the origins of the Maya Royal Court. In: *Royal Courts of the Ancient Maya*, vol. 2. Westview Press, Boulder, pp. 1–45.
- Clark, John E., Pye, Mary E., 2000. The Pacific Coast and the Olmec question. In: Clark, J.E., Pye, M.E. (Eds.), *Olmec Art and Archaeology in Mesoamerica*. National Gallery of Art, Washington DC, pp. 217–251.
- Demarest, Arthur A., 2004. *Ancient Maya: the Rise and Fall of a Rainforest Civilization*. Cambridge University Press, Cambridge.
- Doneus, Michael, Briesse, Christian, Fera, Martin, Janner, Martin, 2008. Archaeological prospection of forested areas using full-waveform airborne laser scanning. *Journal of Archaeological Science* 35, 882–893.

- Dorshow, Wetherbee Bryan, 2012. Modeling agricultural potential in Chaco Canyon during the Bonito phase: a predictive geospatial approach. *Journal of Archaeological Science* 39, 2098–2115.
- Drucker, Philip, 1948. Preliminary notes on an archaeological survey of the Chiapas Coast. *Middle American Research Records* 1 (11), 151–169.
- Ekholm, Susanna M., 1969. Mound 30a and the Preclassic Ceramic Sequence of Izapa, Chiapas, Mexico. *Papers, New World Archaeological Foundation* 25. Brigham Young University, Provo.
- Evans, Susan T., 2008. *Ancient Mexico and Central America: Archaeology and Culture History*, second ed. Thames and Hudson, London.
- Fish, Susan K., Kawalewski, Stephen A. (Eds.), 1990. *The Archaeology of Regions: a Case for Full Coverage Survey*. Smithsonian Institution Press, Washington.
- Fisher, Christopher T., Leisz, Stephen J., Outlaw, G., 2011. LiDAR—a valuable tool uncovers an ancient city in Mexico. *Photogrammetric Engineering and Remote Sensing* 77, 962–967.
- Guernsey, Julia, 2006. *Ritual and Power in Stone: the Performance of Rulership in Mesoamerican Izapan-style Art*. University of Texas Press, Austin.
- Johnston, Kevin J., 2002. Protrusion, bioturbation, and settlement detection during surface survey: the lowland Maya case. *Journal of Archaeological Method and Theory* 9, 1–67.
- Johnston, Kevin J., 2004. The 'Invisible' Maya: minimally mounded residential settlement at Itzán, Petén, Guatemala. *Latin American Antiquity* 15, 145–175.
- Kanter, John, 2008. The archaeology of regions: from discrete analytical toolkit to ubiquitous spatial perspective. *Journal of Archaeological Research* 16, 37–81.
- Kokalj, Ziga, Zaksek, Klemen, Ostir, Kristof, 2011. Application of sky-view factor for the visualization of historic landscape features in lidar-derived relief models. *Antiquity* 85, 263–273.
- Kowalewski, Stephen A., 2008. Regional settlement pattern studies. *Journal of Archaeological Research* 16, 225–285.
- Kowalewski, Stephen A., Feinman, Gary M., Finsten, Laura, Blanton, Richard E., Nicholas, Linda M., 1989. Monte Alban's Hinterland, Part II: Prehispanic Settlement Patterns in Tlacolula, Etla and Ocotlan, the Valley of Oaxaca, Mexico. In: *Memoirs, University of Michigan Museum of Anthropology* 23. University of Michigan, Ann Arbor.
- Ladefoged, Thegn N., McCoy, Mark D., Asner, Gregory P., Kirch, Patrick V., Puleston, Cedric O., Chadwick, Oliver A., Vitousek, Peter M., 2011. Agricultural potential and actualized development in Hawai'i: an airborne LiDAR survey of the leeward Kohala field system (Hawai'i Island). *Journal of Archaeological Science* 38, 3605–3619.
- Love, Michael W., 2002. Early Complex Society in Pacific Guatemala: Settlements and Chronology of the Rio Naranjo, Guatemala. *Papers, New World Archaeological Foundation* 66. Brigham Young University, Provo.
- Love, Michael W., 2007. Recent research in the southern highlands and Pacific Coast of Mesoamerica. *Journal of Archaeological Research* 15, 275–328.
- Lowe, Gareth W., Lee Jr., Thomas A., Espinoza, E.M., 1982. Izapa: an Introduction to the Ruins and Monuments. *Papers, New World Archaeological Foundation* 31. Brigham Young University, Provo.
- Lowe, Gareth W., Ekhlpm, Susana M. Clark, John E., n.d. Middle and Late Preclassic Izapa: Ceramic Complexes and History. *Papers, New World Archaeological Foundation*. Brigham Young University, Provo. Manuscript in possession of the author, dated July 5, 2011.
- Macías, J.L., Espíndola I, J.M., García-Palomo, A., Scott, K.M., Hughes, S., Mora, J.C., 2000. Late Holocene Peléan-style eruption at Tacaná volcano, Mexico and Guatemala: past, present, and future hazards. *Geological Society of America Bulletin* 112, 1234–1249.
- McCoy, Mark D., Asner, Gregory P., Graves, Michael W., 2011. Airborne lidar survey of irrigated agricultural landscapes: an application of the slope contrast method. *Journal of Archaeological Science* 38, 2141–2154.
- Pool, Christopher A., 2007. *Olmec Archaeology and Early Mesoamerica*. Cambridge University Press, Cambridge.
- Pope, Kevin O., Dahlin, Bruce H., 1989. Ancient Maya wetland agriculture: new insights from ecological and remote sensing research. *Journal of Field Archaeology* 16, 87–106.
- Pyburn, K. Anne, 1989. *Prehistoric Maya Community and Settlement at Nohmul, Belize*. In: *BAR International Series* 509. Tempvs Reparatum, Oxford.
- Pye, M.E., 1995. *Settlement, Specialization, and Adaptation in the Rio Jesus Drainage, Retalhuleu, Guatemala*. Unpublished Ph.D. dissertation, Vanderbilt University, Nashville.
- Renslow, Michael S. (Ed.), 2012. *Airborne Topographic Lidar Manual*. American Society of Photogrammetry and Remote Sensing, Bethesda, MD.
- Rosenswig, Robert M., 2007. Beyond identifying elites: feasting as a means to understand early Middle Formative society on the Pacific Coast of Mexico. *Journal of Anthropological Archaeology* 26, 1–27.
- Rosenswig, Robert M., 2008. Prehispanic settlement in the Cuauhtémoc region of the Soconusco, Chiapas, Mexico. *Journal of Field Archaeology* 33, 389–411.
- Rosenswig, Robert M., 2009. Early Mesoamerican garbage: ceramic and daub discard patterns from Cuauhtémoc, Soconusco, Mexico. *Journal of Archaeological Method and Theory* 16, 1–32.
- Rosenswig, Robert M., 2010. *The Beginnings of Mesoamerican Civilization: Inter-regional Interaction and the Olmec*. Cambridge University Press, New York.
- Rosenswig, Robert M., 2012a. Materialism, mode of production and a millennium of change in southern Mexico. *Journal of Archaeological Method and Theory* 19, 1–48.
- Rosenswig, Robert M., 2012b. Agriculture and monumentality in the Soconusco region of Chiapas, Mexico. In: Burger, R.L., Rosenswig, R.M. (Eds.), *Early New World Monumentality*. University Press of Florida, Gainesville, pp. 111–137.
- Rosenswig, R.M., Gasco, J., Antonelli, C.E., Mendelsohn, R.R., Castillo, M.N., Vidal-Guzman, C., 2012. Proyecto de Reconocimiento Regional de Izapa 2011: Informe Técnicos Parciales. Report Submitted to the Consejo de Arqueología, INAH, Mexico City.
- Sanders, William T., Parsons, Jeffery, Santley, Robert S., 1979. *The Basin of Mexico: Ecological Processes in the Evolution of a Civilization*. Academic Press, New York.
- Santley, Robert S., 1990. Demographic archaeology in the Maya lowlands. In: Culbert, T.P., Rice, D.S. (Eds.), *Precolumbian Population History in the Maya Lowlands*. University of New Mexico Press, Albuquerque, pp. 325–343.
- Sharer, Robert J., Traxler, Loa P., 2006. *The Ancient Maya*, sixth ed. Stanford University Press, Stanford.
- Stular, Benjamin, Kokalj, Ziga, Ostir, Kristof, Nuninger, Lanure, 2012. Visualization of lidar-derived relief models for detection of archaeological features. *Journal of Archaeological Science* 39, 3354–3360.
- Verhagen, Philip, Dragut, Lucian, 2012. Object-based landform delineation and classification from DEMs for archaeological predictive mapping. *Journal of Archaeological Science* 39, 698–703.
- Voorhies, Barbara, 1989. Settlement patterns in the Western Soconusco: methods of site recovery and dating results. In: Bove, F., Heller, L. (Eds.), *New Frontiers in the Archaeology of the Pacific Coast of Southern Mesoamerica*. Anthropological Research Papers No. 39. Arizona State University, Tempe, pp. 103–124.
- Voorhies, Barbara, Gasco, Janine, Cackler, Paul, 2011. *Prehistoric Settlement in the South Pacific Coast of Chiapas, Mexico*. *Papers, New World Archaeological Foundation* 71. Brigham Young University, Provo.
- Voorhies, Barbara, Kennett, Douglas, 1995. Buried sites on the Soconusco coastal plain, Chiapas, Mexico. *Journal of Field Archaeology* 22, 65–79.